FOSSIL ENERGY

ORO-5194-1

QUARTERLY PROGRESS REPORT, JANUARY—MARCH 1978 [BLACK SHALE GAS PRODUCTION]

By
Robert C. Shumaker
Keith G. Kirk
E. B. Nuckols III
Brian R. Long
Thomas H. Wilson
Jeanette M. Dixon
J. Negus de Wys

Work Performed Under Contract No. EY-76-C-05-5194

West Virginia University
Department of Geology and Geography
Morgantown, West Virginia

U. S. DEPARTMENT OF ENERGY

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $4.00
Microfiche $3.00

ORO-5194-1
Distribution Category UC-91

QUARTERLY PROGRESS REPORT

U. S. Department of Energy Contract No. EY-76-C-05-5194

January - March 1978

submitted by:

Department of Geology and Geography
West Virginia University

Robert C. Shumaker, Project Director

co-authored by:

Keith G. Kirk, E. B. Nuckols III,
Brian R. Long, Thomas H. Wilson,
Jeanette M. Dixon, J. Negus de Wys,
Principal Investigators

QUARTERLY REPORT: ERDA CONTRACT EY-76-C-05-5194

January - March 1978

Objectives

Collect, compile and analyze geological data and prepare geological structure maps for eastern Kentucky and western West Virginia (fig. 1).

Determine if structural types and styles and surface lineations for productive areas of the Black Shales differ from those in non-productive areas.

Identify and define along with other contractors those geologic parameters that control gas production from the shales.

Determine the feasibility of using shallow penetration resistivity and seismic surveys to detect near surface faults and fractures and demonstrate their relationship to lineations observed on airborne imagery.

Determine if a relationship exists between ground water movement and shale gas productivity.

Develop a method for selecting areas for drilling shale wells that have a potential for gas production.

Organization

In order to attain the stated objectives, we have designed several tasks which have been organized into five study groups. Four of these groups - regional structure studies, fracture studies, structural type studies, and production studies - are carried under the U. S. Department of Energy Resource Inventory Task. One group - geophysical studies - is carried under Shale Characterization Task.

Summary of Progress

Results of our efforts during the winter months came to fruition in the completion of the reports (see publication section below).

The report by de Wys and Shumaker describes an innovative approach to analysis of shale gas production from the Cottageville Field of Jackson County, West Virginia. The reports by Shumaker, Wilson, et al. cover analysis of slickensides found in the shale cores collected during the first two years of the Eastern Gas Shales program in our contract area. Slickensides were generally considered to be compaction features, but our analysis clearly shows that most are related to regional tectonics. Regional analyses and possible ramifications of this discovery to the Eastern Gas Shales program are discussed in the second report by R. C.

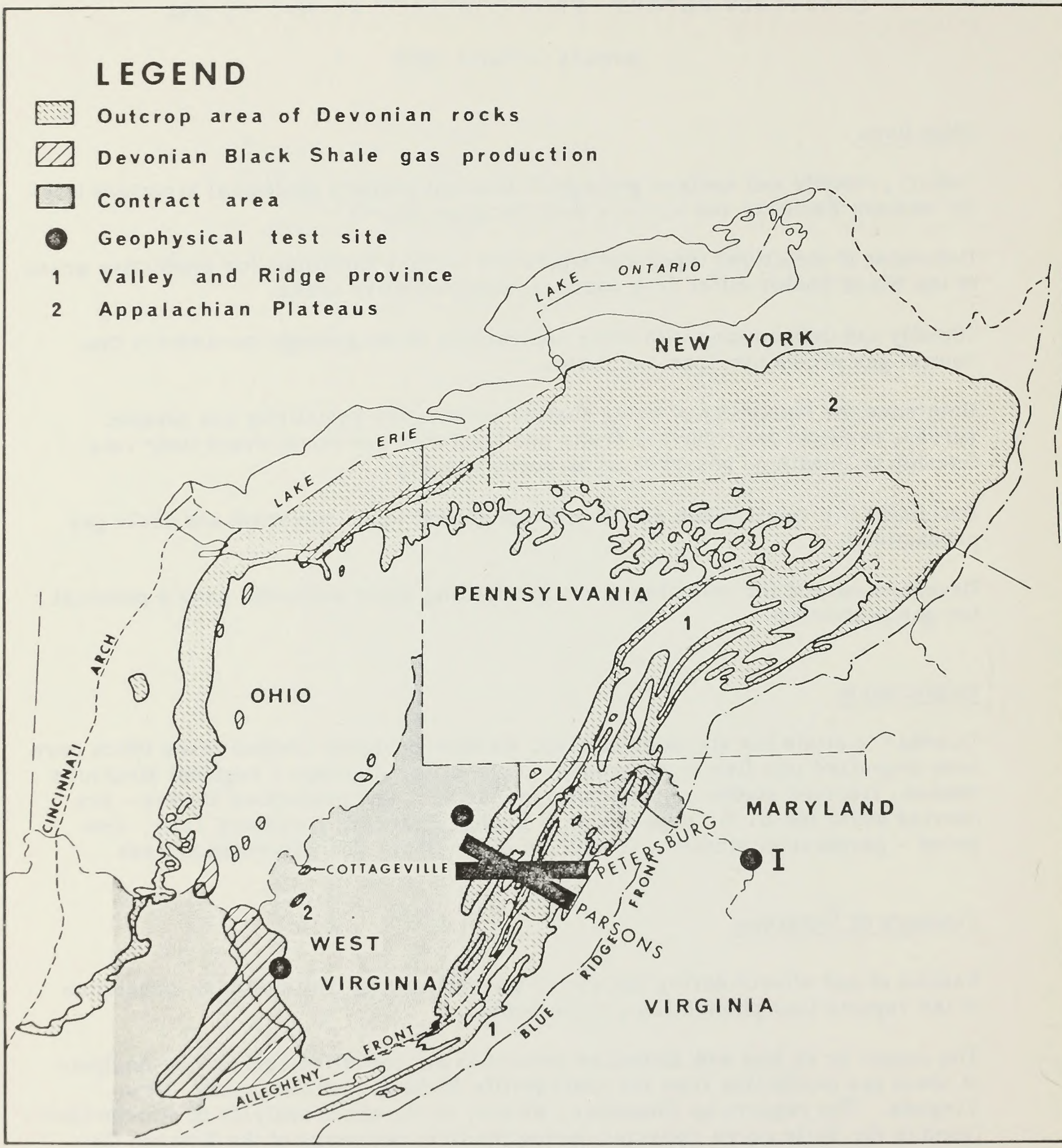
LEGEND
Outcrop area of Devonian rocks
Devonian Black Shale gas production
Contract area
Geophysical test site
1 Valley and Ridge province
2 Appalachian Plateaus
LAKE ONTARIO
NEW YORK
LAKE ERIE
PENNSYLVANIA
OHIO
CINCINNATI ARCH
MARYLAND
COTTAGEVILLE
PETERSBURG
PARSONS
WEST VIRGINIA
VIRGINIA
BLUE RIDGE FRONT
ALLEGHENY FRONT
I
1
2

Figure 1

Shumaker. Wilson, Dixon and Shumaker give detailed results of our structural analyses for each core. The report by Kirk presents the results of geophysical tests run at the first test site.

During this quarter, the Governor of West Virginia, Jay Rockefeller, froze all contract purchases and hiring for all grants. This action was taken because of the United Mine Workers' strike. Special requests and justifications for exemptions were prepared and submitted to the State to cover the hiring of three individuals under this contract to fill the vacancies in the geophysical and the structural tasks. We are awaiting State reaction to these requests.

Requisitions to install the multispectral camera and to purchase a density slice and edge enhancing viewer have been delayed until the freeze is lifted. Thus far, the effect of the strike has been to make progress more difficult, but it has not materially delayed our program. Should the freeze continue through the third quarter, it could materially affect the program since this is a time of field work and data acquisition.

Personnel

Recruiting for a third structural geologist carried under Structural Type Studies was completed and an offer made to a qualified individual. A second geophysicist for Geophysical Studies has been hired and, if approved by the State, should be working by June. During the quarter, we, in conjunction with the Technical Progress Officer, decided to intensify our study of fractures found in the shale. This effort is an outgrowth of our recognition of the "porous fracture facies" described in the reports listed below. This intensification required assigning one geologist from the Structural Types Task and one from the Unconformity Task to the Fracture Studies Task.

Through our efforts, additional geologic and production data will be available for eastern Kentucky gas production; so we intend to expand our program in that area (see production task below).

Travel

Travel by contract personnel beyond normal field work included a trip to Washington D. C. to report results of our geophysical investigation of site I (figure 1) to the Department of Transportation. The report covering our investigation of that site is included below (see Geophysical Task). We also visited the Mining Enforcement and Safety Administration Office in Pittsburgh to inspect and evaluate the optical analysis system they use to evaluate remote sensing data.

Publications

Five papers have been prepared for publication.

For the proceedings volume of the Geological Society of America, Southeastern Section Symposium entitled: Western Limits of Detachment and Related Structure in the Appalachian Foreland:

Shumaker, R. C., 1978, Porous Fracture Facies in Devonian Shales of Eastern Kentucky and West Virginia

Wheeler, R. L., 1978, Cross-strike Structural Discontinuities: Possible Exploration Tool in Detached Forelands

Wilson, T. H., Dixon, J. M., Shumaker, R. C., 1978, Fracture Patterns From Oriented Cores of the Devonian Shale in the Appalachian Basin

For publication in the DOE-MERC orange series:

de Wys, J. Negus and Shumaker, R. C., 1978, Pilot Study of Gas Production Analysis Methods Applied to Cottageville Field

For publication in the proceedings volume of the Department of Highway Conference on geophysical evaluation of the Forest Glen metro site:

Kirk, Keith G., 1978, High Resolution Seismic Survey at Forest Glen, 11 p.

Finances

A separate report will be submitted by the Comptroller through the West Virginia University Grants and Contracts Office concerning the exact status of our finances.

The minor problems concerning finances outlined in our last quarterly report were discussed and resolved in concert with our Technical Progress Officer.

I. STATUS OF RESOURCE INVENTORY TASKS

1. REGIONAL STRUCTURE - R. C. Shumaker (Project Director)

As noted in the previous quarterly report, we diverted a major part of our effort from structural type studies into an area that needed study; detailed structural analysis of oriented shale cores. The results of these efforts are detailed in two reports written this quarter:

1. Shumaker, R. C., 1978, Porous Fracture Facies in the Devonian Shales of Eastern Kentucky and West Virginia
2. Wilson, T. H., Dixon, J. M., Shumaker, R. C., 1978, Fracture Patterns From Oriented Cores of the Devonian Shale in the Appalachian Basin

The essence of results of these studies indicates that slickensides are not random as thought by many workers in the project, but they occur on oriented fractures within the productive porous facies of the highly organic portions of the shale. These fractures may provide the key for determining the origin of all fractures within the productive zone. More work is required to establish the interrelationships of fractures in the porous zone. During the upcoming summer data will be collected from cores, field work in the Devonian shales of Kentucky, Ohio, and Virginia to determine the extent and nature of fractures within the productive portions of the Devonian shale section. Interrelationships of mineralized vertical fractures and slickensided shear fractures of the porous fracture facies will be studied in more detail.

Tops for all wells penetrating the base of the Cambrian Knox dolomite were spotted on the 1:250,000 base maps and interpretive contouring was started this past quarter. Contour interpretation will be completed during the upcoming quarter on this structural map.

2. STRUCTURAL TYPE STUDIES - T. H. Wilson

Analysis of fracture and slickenside data provided by the West Virginia Geological Survey from several cored wells in the Devonian shale has been completed. The results of this analysis have been prepared as a manuscript to be included in the proceedings volume of the Southeastern Section Symposium of the Geological Society of America on Western Limits of Detachment and Related Structure in the Appalachian Foreland The paper, entitled: Fracture Patterns From Oriented Cores of the Devonian Shale in the Appalachian Basin, is authored by T. H. Wilson J. M. Dixon, and R. C. Shumaker.

A detailed statistical analysis of bedding orientation data collected from the Middle Mountain syncline has been completed. Several maps constructed from this data will be used to examine the internal structures of the syncline, and to define the width of the Parsons structural lineament in this area (figure 1). Work has begun on a manuscript which will discuss the use and interpretation of bedding orientation data. This manuscript will not be completed until additional information can be gathered from the Middle Mountain area.

The Ph.D. dissertation, covering the work I am to accomplish under the contract was presented orally to the committee members for their consideration. The proposal was accepted.

Jeanette M. Dixon

The analysis of slickensides found in the cores from Cottageville wells #11940 and 12041, Lincoln County wells #20402 and 20403, and Mason County well D.K. #3 has been completed. Detailed results will be made available in the Report by Wilson, T. H., Dixon, J. M., and Shumaker, R. C.

Preliminary field work has been done in preparation for the fracture study in the Parsons area. This study will begin full time in May, 1978. Methods for measuring joint frequency and operator variability are being tested.

3. FRACTURE STUDIES - Brian R. Long

The fracture study has progressed during the last quarter in the visual and statistical display of joint data collected in the study area of eastern Kentucky. Visually the joint strike data has been plotted by computer as rose diagrams on the 1:250,000 base map scale. Separate map plots have been completed for coal, limestone, sandstone, and shale lithologies within the study area. In addition, designations of systematic and cross jointing sets have been added to the plots where available. During the next quarter comparisons of the joint strike roses and structural features will begin.

Statistically the data has been subdivided into lithologic groups and several tests to determine possible relationships between bedding thickness, joint frequency and strike direction have been attempted. First, scatter plots and contingency tables were made to better visualize these possible relationships. Second, linear and nonlinear regression has been run to test the relationships. Results are far from conclusive due to the need for further data set corrections and further testing. To date, little correlation between bedding thickness and frequency has been found in shale. The limestones and sandstones have shown approximately 50% correlation between bed thickness and frequency. No correlation has yet been found between frequency and joint strike direction; however, testing in this area is not complete. During the next quarter these and other tests will be continued.

4. PRODUCTION STUDIES - E. B. Nuckols III

Production analysis of the Cottageville Gas Field near Ripley, West Virginia, was concerned with computer analysis of production data and the final gathering of all readily available well and production data. Early in the quarter, Mr. Alan Cevtnick of MERC was asked to run certain production analysis tests on production data obtained from Consolidated Gas Supply Corporation, Columbia Gas, and Cities Service. The following type of production analysis was completed:

1. Production decline: declines for 41 wells with extrapolation to economic limits and potential gas reserves.

2. Decline curve analysis was grouped into summary form.

3. Decline curve slopes were computed for five year intervals.

In addition to the production analysis, a well status map of shale wells was completed along with a graphical representation of pressure decline for shale wells in the gas field.

A final compilation of data was made during this quarter, with the obtaining of drilling, completion, and other drilling particulars from the Devon Corporation. With this additional data acquisition, there will be a termination of data collection. All existing data on hand will now be analyzed and be organized into a final report. During the upcoming quarter, all analysis will be made and a rough draft of the final report will be completed.

J. Negus de Wys

Cottageville Production Study - The final copy of "Pilot Study of Gas Production Analysis Methods Applied to Cottageville Field" was submitted to MERC.

Eastern Kentucky Gas Field - Maps from a trend study have been obtained. Maps showing 1) total wells in the field, 2) gas wells with $>$ 2 MMcf initial open flow, 3) gas wells with $>$ 1 MMcf initial open flow, and 4) gas wells with $>$500 Mcf initial open flow are included.

Release by five companies of a seismic basement structure map is being negotiated.

Samples from one well in each of ten counties in the study area have been located and are being shipped to West Virginia University. Microscopic lithologic examinations, examination of the Foerstia zone in Middle Huron, and geochemical analysis will be performed on these samples.

Arrangements have been made with Dr. Renton for the elemental and mineralic identifications using XRF and XRD.

Geophysical logs are being correlated. A base map with a grid of cross sections has been completed. The first cross section running NW-SE on the eastern edge of the field is nearing completion.

Arrangements have been made with the West Virginia Geological Survey for digitization of the nearly 5000 gas producing wells in the field. This is preliminary to computer analysis of production and geological geochemical data. A computer card data input sequence is being developed by a computer programmer.

A library computer search strategy has been developed with the main sets being Paleoecology, Geochemistry, and Devonian Shales. This search will be run by the University of Utah facility and cover all search bases from 1965 to the present in foreign and U. S. literature. Titles and abstracts are being requested.

Request has been made for personnel assistance commencing in June for proper coverage of a task which has gone from 300 to 5000 data points. This increased data base will insure higher integrity of results.

II. STATUS OF SHALE CHARACTERIZATION TASKS

GEOPHYSICAL STUDIES - Keith G. Kirk

The second quarter of 1978 was spent performing initial field testing on the High Resolution Seismic (HRS) system, analyzing the results of these tests, developing seismic modeling programs and designing and constructing a new seismic energy source.

The field testing took place at a Department of Transportation test site in Forest Glen, Maryland. The system was tested under extremely adverse conditions that included high noise and excessive earth attenuation problems. In order to properly analyze this data, seismic modeling programs were set up and the data was analyzed. A report briefly summarizing the results of the initial testing is appended to this quarterly report.

Experience at the test site led to the development of a new energy source that more efficiently transmits the high frequency seismic waves to the subsurface. The energy source is an acetylene canon that is placed down a shallow bore hole and fired electrically six times per minute. This instrument has been constructed and will be tested very early in the third quarter.

The majority of the third quarter will be spent collecting the field data and analyzing same.

HIGH RESOLUTION

SEISMIC SURVEY

AT

FOREST GLEN

Submitted to;

United States Department of Transportation
Federal Highway Administration

Submitted by:

Keith G. Kirk
Department of Geology and Geography
West Virginia University
Morgantown WV. 26505

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

This research was funded by contract to the Department of Energy-MERC. The field work from which this report follows was performed from December 15 to December 20, 1977 under a separate contract to the Department of Transportation.

A shallow high resolution reflection seismic system developed at West Virginia University was used in order to evaluate its usefulness as a geotechnical site exploration tool. The high resolution seismics (HRS) as used in this investigation is a surface technique. Energy is imparted to the subsurface by impacting the ground with a hydraulically driven ram that strikes the ground with 30,000 lbs. of force. This energy source is capable of generating frequencies upwards to 350 Hz.

The energy once imparted to the subsurface travels down until it encounters a velocity boundary. At this boundary the energy is partitioned and a portion of the energy is reflected back to the surface where it is detected; a portion passes through this velocity boundary to be partitioned and reflected off of the next velocity contrast and so forth.

The time from which the energy is imparted into the ground until it returns to the detectors at the surface is the critical parameter that is measured to determine the depths to the various velocity boundaries. These velocity boundaries correspond to material boundaries in the subsurface.

The accuracy which is achievable by the HRS method of subsurface investigation is largely dependent on the frequency of the energy that is imparted into the ground. Figure 1 illustrates the relationship between velocity, frequency, and obtainable resolution. Velocity is an uncontrollable variable and varies from site to site. It can be readily seen that the smallest resolvable bed is inversely dependent upon the frequency. That is to say, the higher the frequency that can be transmitted through the ground and detected, the more reliable is the depth determination to the various earth layers. This is also, of course, dependent on an accurate determination of the velocity distribution within the subsurface. This factor will be addressed later in this report.

There are several problems inherent in transmitting and detecting high frequency seismic waves within the earth. Before these problems are discussed, one must first define what is meant by high frequency seismic waves. Generally, frequencies over 100 Hz are considered high frequency in terms of seismic exploration.

The first problem with using high frequency waves as an exploration tool is that the earth acts as a natural filter for these frequencies. Figure 2 illustrates a generalized graphical display of the attenuation caused by average earth conditions as a function of frequency. It can be seen from this diagram that earth attenuation has an exponential dependence on frequency. This relationship presents problems in the detection of high frequency signals. It follows that given an energy source that transmits energy equally over a given range of frequencies that, at the detector, the low frequency arrivals will be received at a

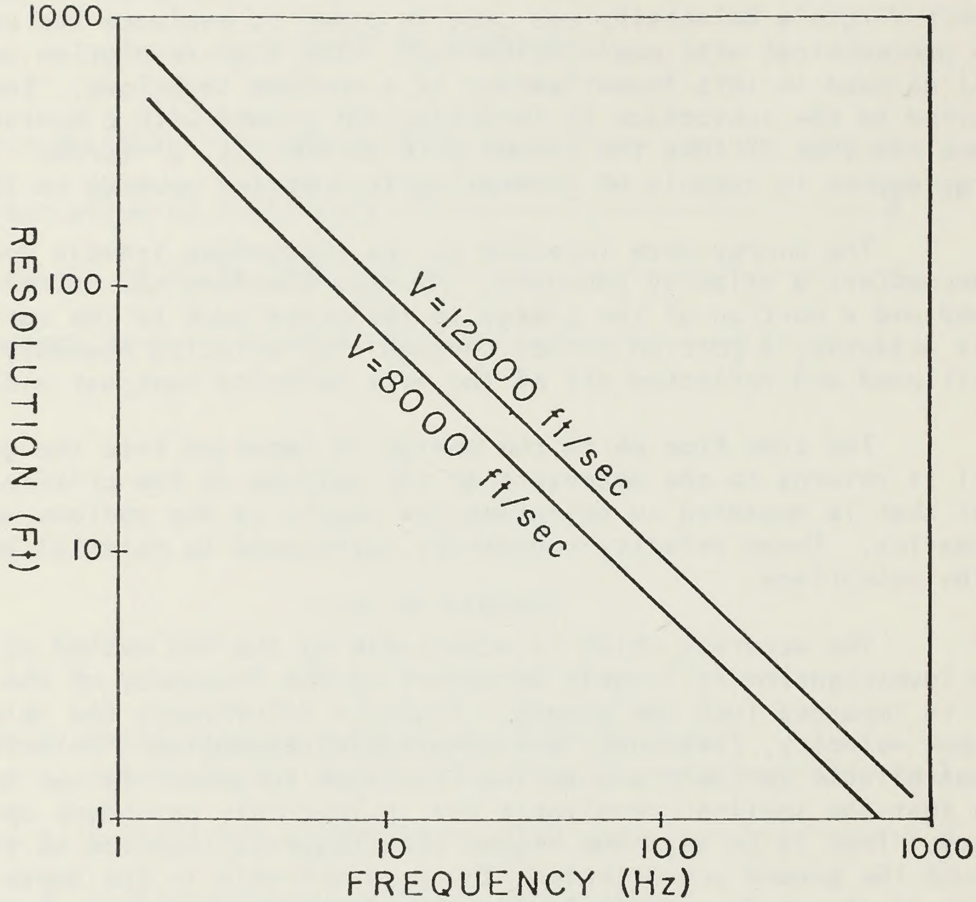

Figure 1 Resolution as a function of frequency for velocities common to the Forest Glen site.

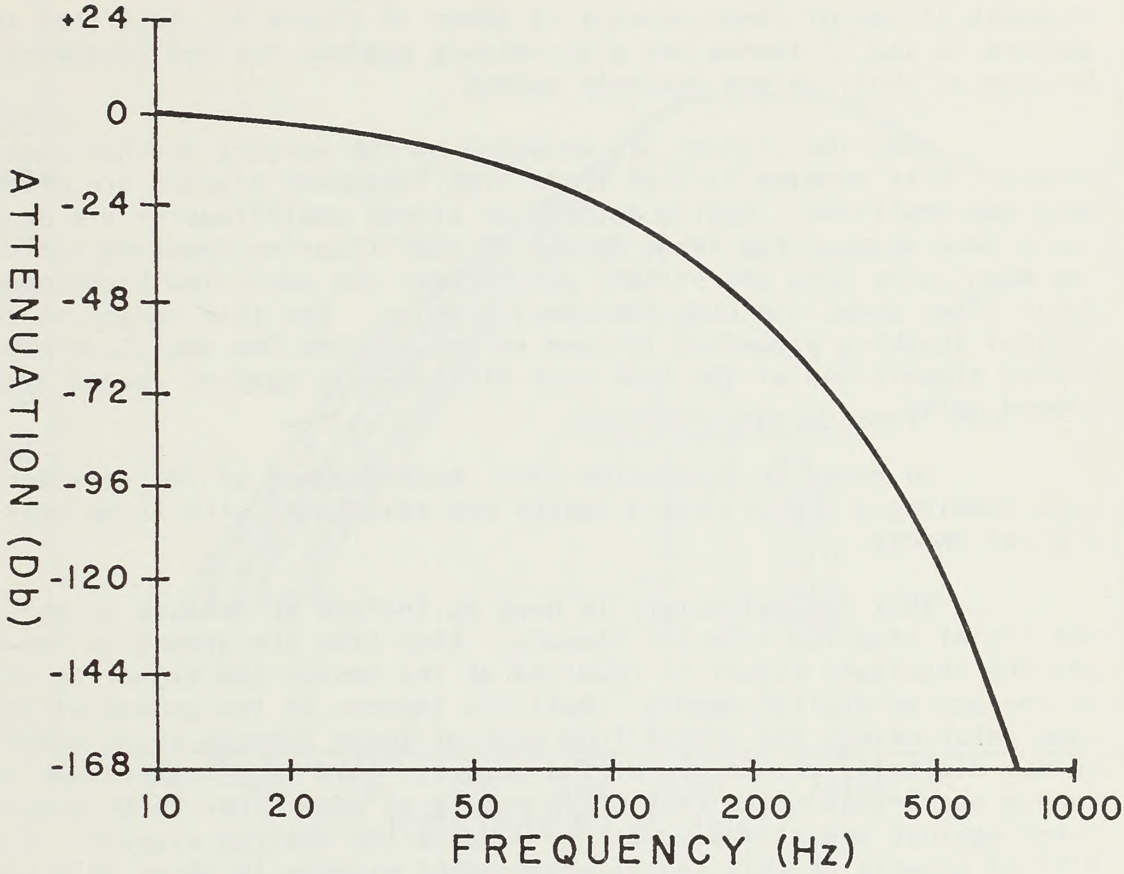

Figure 2 Generalized earth attenuation curve

much higher amplitude than the high frequency waves. This usually means that the high frequency signals are lost amongst the low frequency waves.

In order to alleviate this problem a combination analog filter and amplifier is used whose filter and amplification function can be adjusted to approximate the inverse of the earth attenuation function shown in Figure 2. The response of this filter at one of its available gain settings is shown in Figure 3.

Signals are detected with special purpose sensors or geophones that are designed specifically to detect high frequency waves. The response of one of these sensors is shown in Figure 4. Note that the sensors in and of themselves discriminate against the low frequency waves because of their unique response curves.

Once the signals are detected by the sensors another problem exists. This problem is that these high frequency signals are often of very low amplitude. Analog methods of signal amplification are not applicable here because the large degree of amplification required introduces too much noise into the system, and further the amplified background noise often masks the high frequency signals. For this reason an in-field digital stacking procedure is used to enhance the low amplitude high frequency signals and at the same time discriminate against random background noise.

In order to accomplish this, each channel of the seismograph that receives a signal from a sensor has associated with it an active digital memory.

This digital memory is used as follows to enhance or amplify the signal received from the sensors. Each time the ground is impacted and the resultant signal is received at the sensor the signal is stored in the active digital memory. Multiple impacts of the ground at the same point permit the signal from each of these impacts to be added together digitally within the active memory. This in effect allows the random background noise that often exists at many sites to be discriminated against and at the same time enhance the desired signals. A simplified example of this signal enhancement process is shown in Figure 5. Note that after the initial impact, the reflection is not readily discernible from the background noise but as the impacts are added together the reflection becomes much more apparent.

Once the signals from each channel of the seismograph are enhanced to an easily recognizable form they are played onto a digital recorder for later processing back at the computer center at West Virginia University. This data is then processed as any other seismic data.

In order to obtain an accurate determination of depth to the various boundaries of the different earth materials it is crucial that an accurate determination of the velocity distribution in the subsurface is known. Often it is difficult to obtain accurate velocity information at small construction sites where space constraints limit the length of the geophone spread. For this reason at such sites it is necessary that the velocity data be obtained by down hole velocity logging techniques.

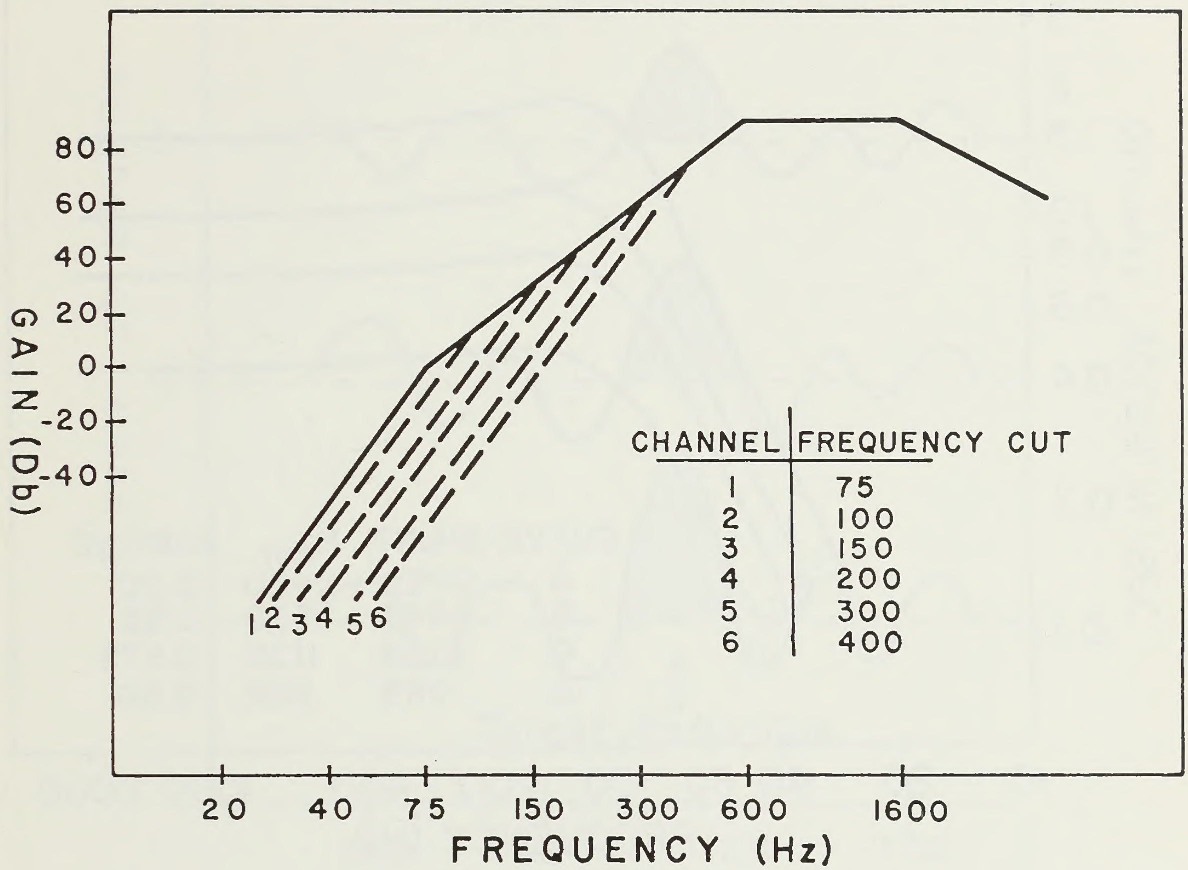

Figure 3. Amplifier response curve for a given gain setting.

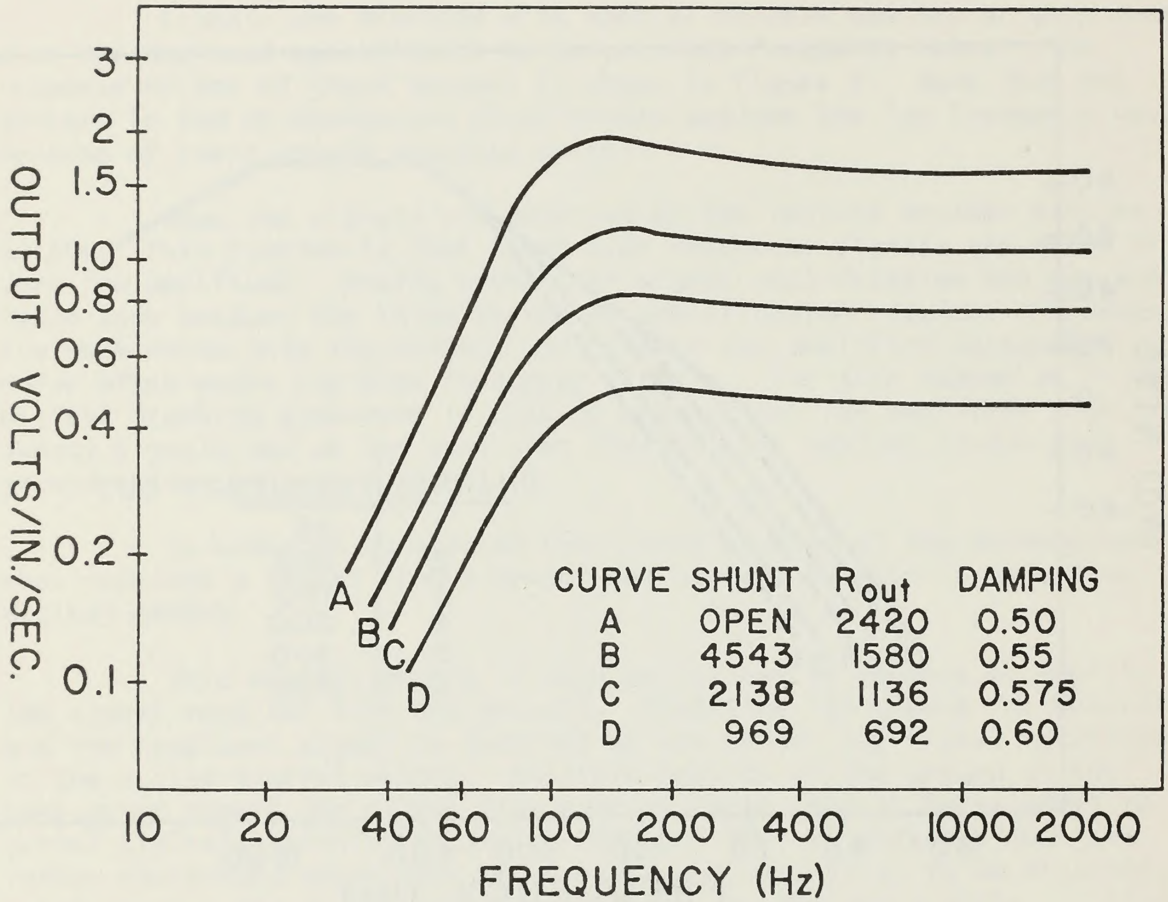

Figure 4 Geophone response curve

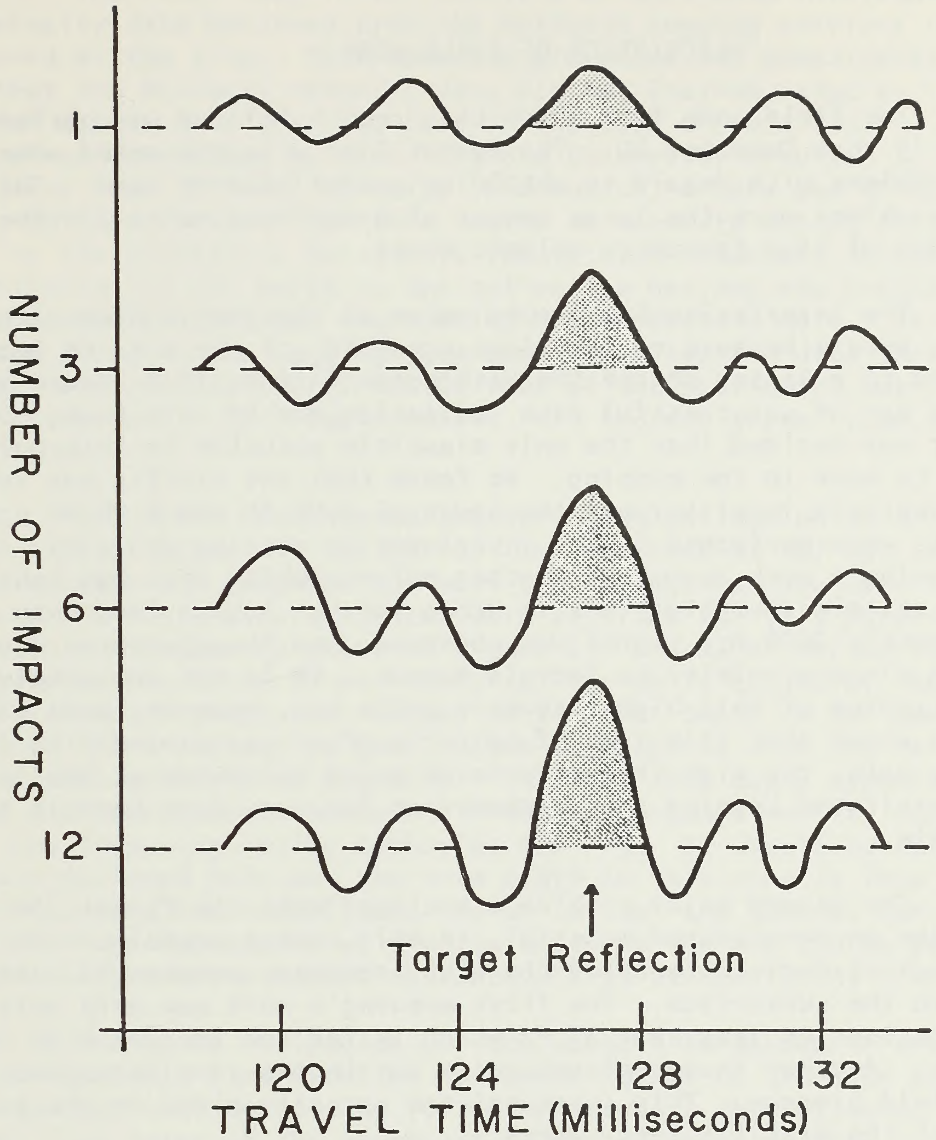

Figure 5 Simplified example of signal enhancement process. As the number of impacts increase the target reflection becomes more apparent.

At the Forest Glen site this velocity logging was performed by Birdwell. It is this velocity data that was used to interpret and model the seismic reflection data in this report.

DESCRIPTION OF FIELD WORK

The field work from which this report follows was performed on December 15 thru December 20. The Forest Glen site presented some difficult problems with regard to obtaining useful seismic data. The two biggest problems were the large amount of background noise and the large attenuation of high frequency seismic waves.

The interfering background noise at the Forest Glen site was extremely severe because of the close proximity of the site to Georgia Avenue and to a lesser degree the Washington Beltway (U.S. Route 495). After one day of unsuccessful data collection due to this background noise, it was decided that the only plausible solution to this noise problem was to work in the evening. We found that the traffic was reduced to an acceptable level between the hours of 1:00 AM and 6:00 AM provided that tests were performed during interludes in passing vehicles. The first evening's work uncovered another noise problem that has been noted by other seismic investigations in urban areas. A high frequency (approximately 2000 Hz) signal was observed when the geophones were placed in close proximity to Georgia Avenue. It is not completely certain what the source of this high frequency noise was; however, past experience has shown that this type of noise is often associated with a leaking water main, the high frequency noise being generated at the leak. This necessitated keeping the geophones as far away from Georgia Avenue as possible.

The second major problem associated with the Forest Glen site is that the unconsolidated material, in this case a saprolite overlying the bedrock strongly attenuated the high frequency components transmission to the subsurface. The first evening's work was only able to detect frequencies less than 37 Hz which is far too low for high resolution work. Another inconvenience was a continuous rain throughout the entire field program. This inconvenience actually aided in the transmission of the high frequency waves.

During the fourth evening of field work the ground apparently became saturated to the point where high frequency waves could be transmitted. At this time, frequencies up to 154 Hz were transmitted and received by the HRS system. This frequency (154 Hz) was the highest frequency that the earth materials transmitted successfully at the Forest Glen site. One hundred fifty-four Hz was a much lower frequency than what was originally anticipated that could be used at the site. It had been anticipated that 350 Hz could be used here but this estimate was incorrect.

Because of space constraints and obstructions such as trees and trailers along with the high frequency noise problem associated with Georgia Avenue, the only successful seismic line was that line that ran from the southeast corner of the site to the northwest corner.

ANALYSIS OF FIELD DATA

The first step in the analysis of this data involved modeling the velocity data obtained from the Birdwell logging services that were performed at the site. This modeling procedure was complicated by the fact that the Birdwell velocity data did not include velocity information for depths less than 100 feet in the case of hole T-3. A preliminary refraction survey by West Virginia University resulted in near surface (less than 30 feet) velocity information; a data gap of approximately 60 feet exists. For this reason an accurate determination of the depth to the reflection horizon is impossible. However, a reasonable determination of the depth to the reflecting horizon was possible based on the comparison between the modeled data and field data. It was assumed, based on the logging data and the refraction data that the average velocity for the first 100 feet of unconsolidated material was 4500 feet/second. This would result in a two way travel time of 44 milliseconds.

The field data showed the strongest reflection at a two way travel time of 57 ms. A reflection also occurred at 167 ms. A synthetic seismogram was prepared for well T-3. Programs developed at the Morgantown Energy Research Center were utilized for this purpose. The synthetic seismogram is shown in Figure 6. The major reflection occurs at approximately 53 to 60 ms. This reflection is caused by the high reflection coefficient that occurs at 119 feet depth on the modeled test hole T-3. This reflection coefficient corresponds with the reflection coefficients at 47 ms on Figure 6. This 119 foot depth appears to correlate with the transition point in the gamma-gamma density logs provided by the Tennessee Valley Authority for T-3. It should be noted that T-3 is a deviated hole and the true depth to this zone is less than 119 feet. However, the significant factor is that the density contrast at this point was detectable at shallow depth by the HRS system even under the extremely adverse conditions encountered at the Forest Glen site.

The 53 ms reflection horizon appears to deepen as one moves along the seismic line from the northwest corner of the site to the southeast corner. Correcting for normal moveout the reflected horizon arrives 7 ms later at the southeast corner of the site than at the northeast corner. From examining the available boring data, it appears as if this reflection horizon is caused by the physical transition between the weathered rock and the highly jointed rock as indicated on drawing F-G-82B.

The reflection at 167 ms occurs below the depth of investigation and since there is no available velocity data at this time interval a depth determination cannot be made.

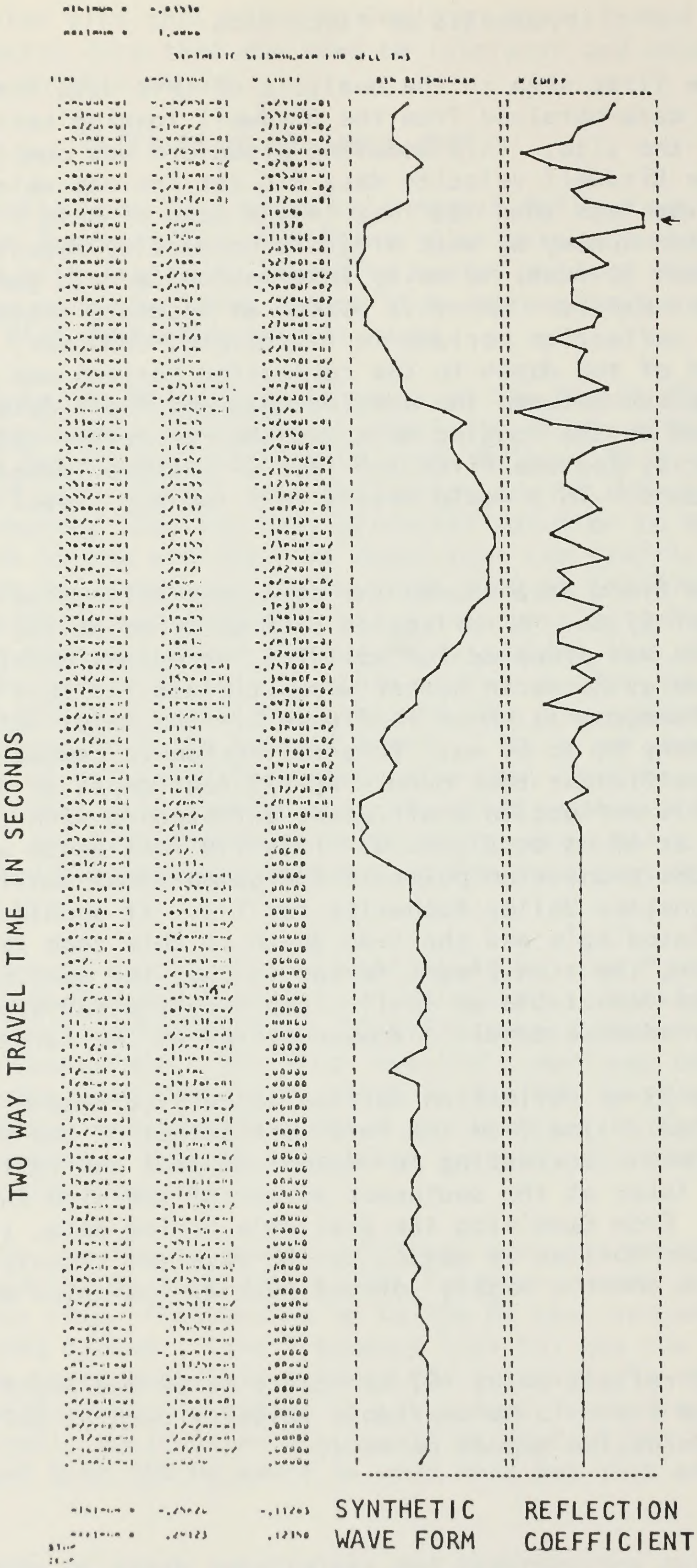

Figure 6 Synthetic seismogram taken from velocity data from test hole T-3. The synthetic wave form and reflection coefficient are plotted against two way travel time.

SUMMARY

The HRS survey performed at the Forest Glen test site was not extremely successful in detailing the subsurface. Primarily this was for two reasons, the large quantity of noise at the site and the unconsolidated materials' large attenuation of the high frequencies that are required for the high resolution work. The maximum detectable frequency was 154 Hz. It had been expected that at least 350 Hz could be used at the site. The 154 Hz frequency limited the resolution of the survey.

The noise at the test site prevented all but one successful seismic line. This line showed a strong reflection at 53 milliseconds. The reflection corresponds to a depth of approximately 120 feet based on a synthetic seismogram generated from the velocity data of deviated bore hole T-3. An accurate determination of the depth to this reflection is not possible since there is a 60 foot gap in the available velocity data.

The reflecting horizon associated with the 53 ms reflection deepens from the northwest corner of the site towards the southeast corner.

It would appear that from this test data that the HRS system, that has proved so effective in the sedimentary terrain of West Virginia, has limited application in igneous terrains due to the occurrence of thick saprolites that attenuate the high frequency waves to a large degree.

Seismic surveys can be successfully performed in urban areas provided the data is collected late at night to minimize the effects of noise created by traffic.

☆U.S. GOVERNMENT PRINTING OFFICE: 1978-740-420/242